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Review

Techno-economic review of solar cooling technologies based on location-specific data☆

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ABSTRACT

Solar energy can potentially contribute to 10% of the energy demand in OECD countries if all cooling and heating systems would be driven by solar energy. This paper considers cooling systems for residential and utility buildings in both South and North Europe and investigates the most promising alternatives when solar energy is to be used to supply the cooling demand of these buildings while the heat rejection temperatures are high. Both the solar electric and solar thermal routes are considered. The discussion considers both concentrating and non-concentrating thermal technologies. It is concluded that presently vapor compression cycles in combination with PV collectors lead to the economically most attractive solutions. The second best option are vapor compression cycles driven by electricity delivered by parabolic dish collectors and Stirling engines. The best thermally driven solution is the double-effect absorption cycle equipped with concentrating trough collectors closely followed by desiccant systems equipped with flat-plate solar collectors. Adsorption systems options are significantly more expensive.

Synthèse techno-économique des technologies du froid solaire basé sur des données spécifiques à la localisation

Mots clés : Froid, Froid solaire ; Capteur solaire ; Refroidissement solaire ; Système à compression ; Système à sorption

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Nomenclature

A	area (m^2)
COP	Coefficient of Performance
CPDC	concentrating parabolic dish collector
CPTC	concentrating parabolic trough collector
CSP	concentrating solar power
DE	double effect
ETC	evacuated tube collector
FPC	flat plate collector
HE	half effect
I_p	solar radiation perpendicular to collector surface ($W\ m^{-2}$)
OECD	Organisation for Economic Co-operation and Development
PV	photovoltaic panel
Q	heat transfer rate (W)
SE	single effect
T_H	temperature of high-temperature reservoir (K)
T_C	temperature of low-temperature reservoir (K)
T_M	heat rejection temperature (K)
T_{panel}	temperature PV panel (°C)
W	power (W)

Greek

α	second law efficiency
η	efficiency

Superscripts

id	ideal

Subscripts

a	absorber, ambient
c	condenser
cool	cooling
e	evaporator
el	electrical
g	generator
heat	driving heat
pow	mechanical power
s, sol	solar radiation, solar collector
STC	standard test conditions

1. Introduction

Solar energy is the main source of energy for our planet. Hermann (2006) illustrates the availability of exergy in the terrestrial environment. Most of the solar radiation reaching the terrestrial environment is dissipated and only a very small amount is converted into solar energy (959 PJ $year^{-1}$ while 1,356,048,000 PJ $year^{-1}$ are dissipated only into surface heating). IEA (2013) reports the worldwide solar conversion in 2011 of 711 PJ (74%) thermal, 234 PJ (24%) PV and 14 PJ (2%) concentrating solar power, in total 959 PJ $year^{-1}$. The potential of solar energy use is thus huge.

Fig. 1 shows the distribution of the energy consumption in the residential sector of OECD member countries in 2011 (IEA, 2013). The total yearly energy consumption of 25,000 PJ is a small fraction of the solar energy dissipated into surface heating. Space heating consumed almost 50% of the total (12,350 PJ) while space cooling consumed 6% (1610 PJ). The sector "services" which includes utility buildings is not included in these numbers but also consumes large amounts of energy for heating and cooling purposes (estimated around 7000 PJ). This indicates that about 10% of the energy use of OECD countries (225,752 PJ) has the potential to be served by solar driven refrigeration/heat pump cycles. Although solar cooling is mainly considered for removing cooling loads from the applications, the same cycles used as heat pumps will also have an advantage in comparison to the direct use of solar heat for heating purposes.

The first step in the evaluation of solar cooling systems is the identification of the demand side: which applications would preferably be served with solar cooling and how does the cooling demand vary as a function of time. In this study we distinguish between residence air conditioning, utility buildings conditioning and freezing applications. Freezing applications will have very specific requirements and will not be discussed in this paper. Fig. 2 shows representative summer cooling load requirements for residences of approximately 150 m^2 in Central Spain and the Netherlands (Hosseini, 2010). The utility building cooling load profile for Northern Europe has been taken from Paul (1995). The peak cooling power requirement for the utility building in Spain has been taken from the ratio of the peak cooling power requirements of residential buildings of the Netherlands and Spain. The figure also shows the peak solar radiation for the corresponding locations during the same period. The scale has been adjusted to accentuate the correspondence between solar radiation availability and cooling load requirement.

Table 1 shows the values derived from Fig. 2 which will be considered in the further discussions. These values apply for peak conditions and it will be assumed that cooling systems will be designed to fulfill the corresponding cooling power requirements. The process side heat rejection temperatures are assumed to be 10 K higher than the environmental temperatures.

Considering that cooling demand increases with the intensity of solar radiation, solar cooling is considered as a logical solution. There were many projects for development or demonstration of solar cooling technologies and solar cooling

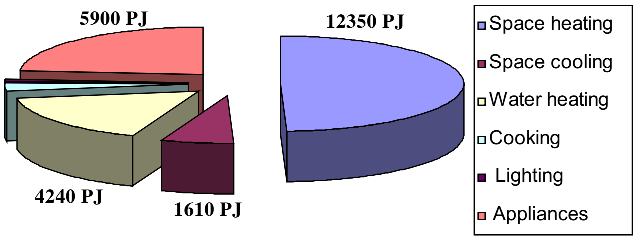

Fig. 1 – Energy use in the residential sector of OECD countries during 2011 (total is 25,000 PJ).